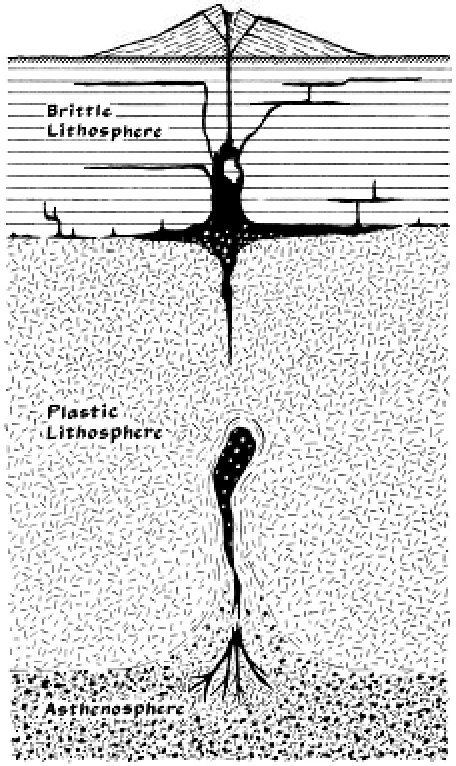
Magma Generation and Evolution

Magma Generation

- Partial melting
  - Upper mantle
  - Deep crust
- Magma density
- Less than surroundings



Magma generation is initiated by melting due to:

1) a rise in temperature,
2) a release of pressure,
3) an influx of volatiles, or
4) a combination of these mechanisms.

What Makes Magma Rise?

Compared to the unmelted *country rock*, magma is buoyant:

- Rock becomes less dense when liquid and tends to rise like a balloon in air.
- The pressure of solid rock squeezes liquids toward overlying areas of lesser pressure.

◄ Looking Glass Rock, North Carolina.

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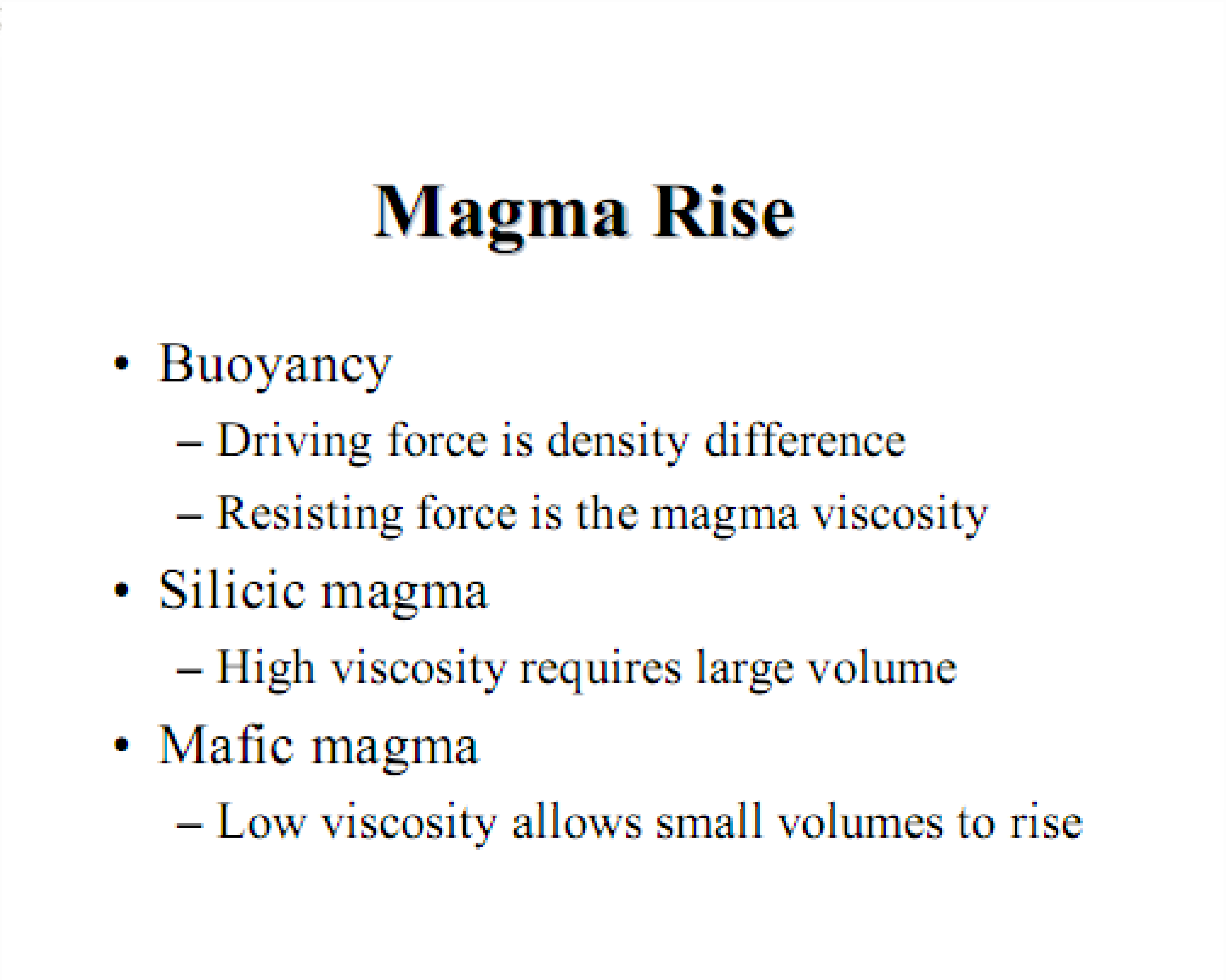
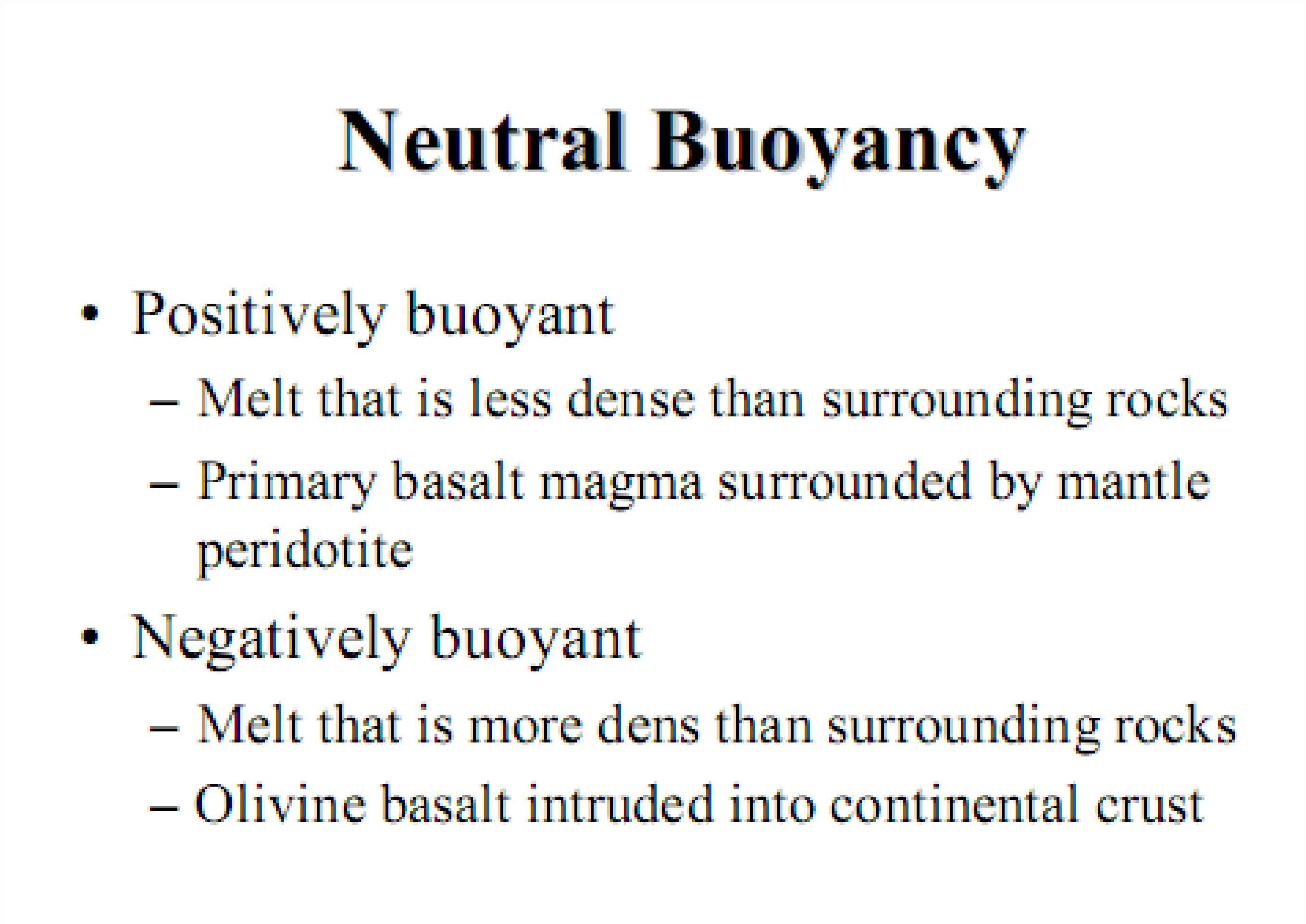


Magma Rise

- Buoyancy
  - Driving force is density difference
  - Resisting force is the magma viscosity
- Silicic magma
  - High viscosity requires large volume
- Mafic magma
  - Low viscosity allows small volumes to rise



Neutral Buoyancy

- Positively buoyant
  - Melt that is less dense than surrounding rocks
  - Primary basalt magma surrounded by mantle peridotite
- Negatively buoyant
  - Melt that is more dens than surrounding rocks
  - Olivine basalt intruded into continental crust

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How Can Dense Magma Rise?

- Volumetric expansion on melting?
- Exsolution of bubbles?
- There must be another cause.

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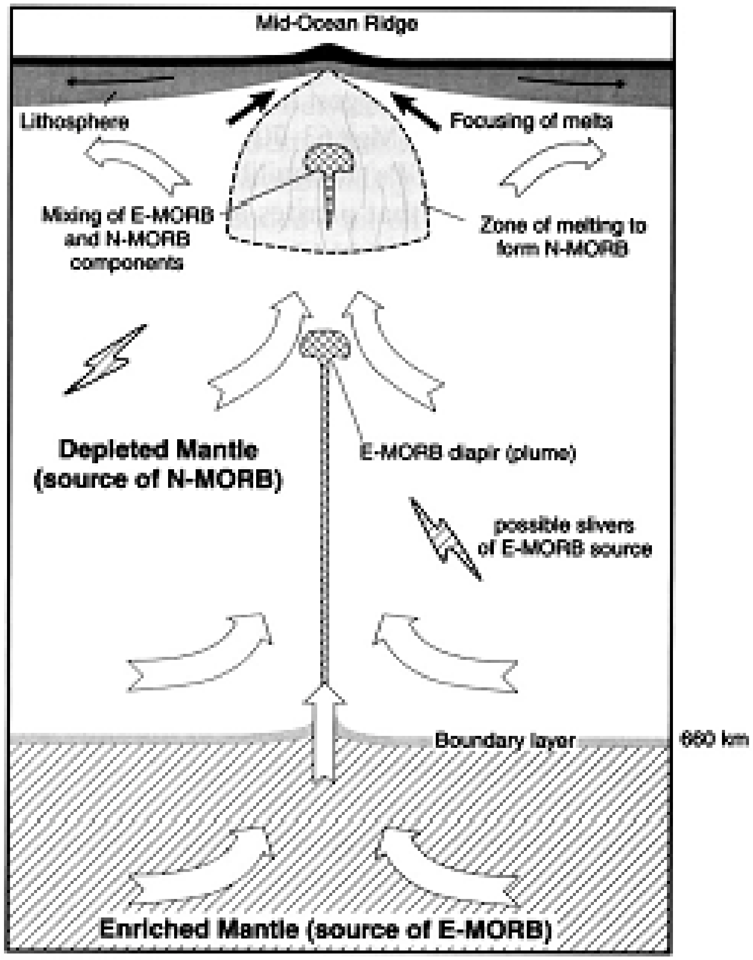
Energy Sources

- Thermal energy
  - Melting caused by decompression or volatile flux
- Gravitational energy
  - Driven by density differential

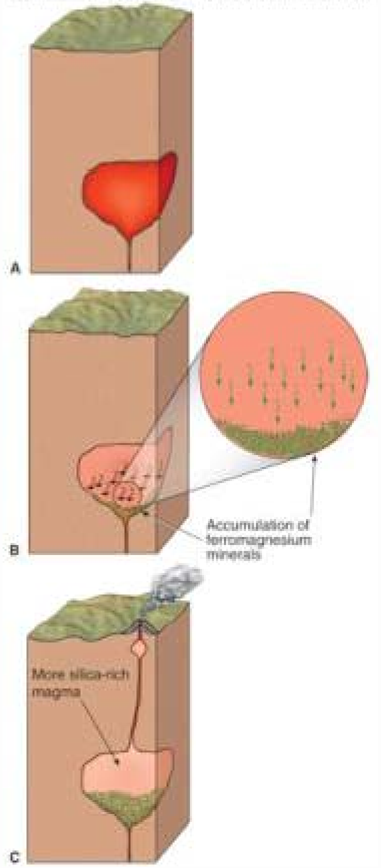

Mid-Ocean Ridge
Lithosphere
Focusing of melts
Mixing of E-MORB and N-MORB components
Zone of melting to form N-MORB
Depleted Mantle (source of N-MORB)
E-MORB diapir (plume)
possible slivers of E-MORB source
Boundary layer
660 km
Enriched Mantle (source of E-MORB)

There are two type of magma:

- Primary magmas ➔ those most like their source rocks
- Derivative magmas ➔ those have undergone some sort of differentiation or contamination.

Magma Evolution

- A change in the composition of a magma body is known as *magma evolution*
- Magma evolution can occur by *differentiation*, *partial melting*, *assimilation*, or *magma mixing*
- *Differentiation* involves the changing of magma composition by the removal of denser early-formed ferromagnesian minerals by *crystal settling*
- *Partial melting* produces magmas less mafic than their source rocks, because lower melting point minerals are more felsic in composition



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Differentiation

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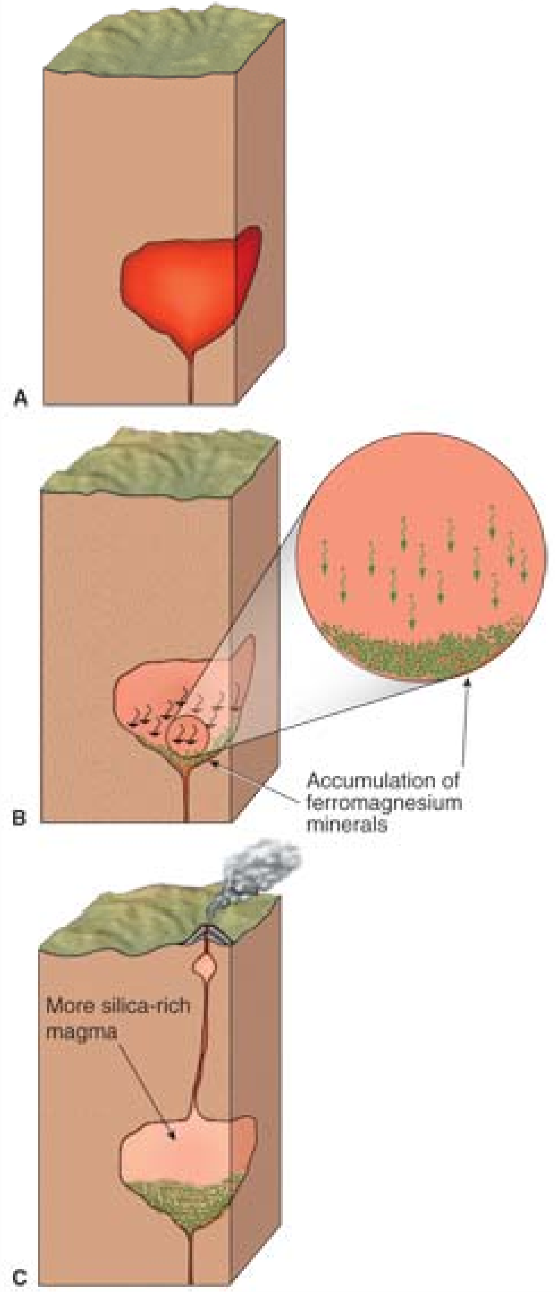
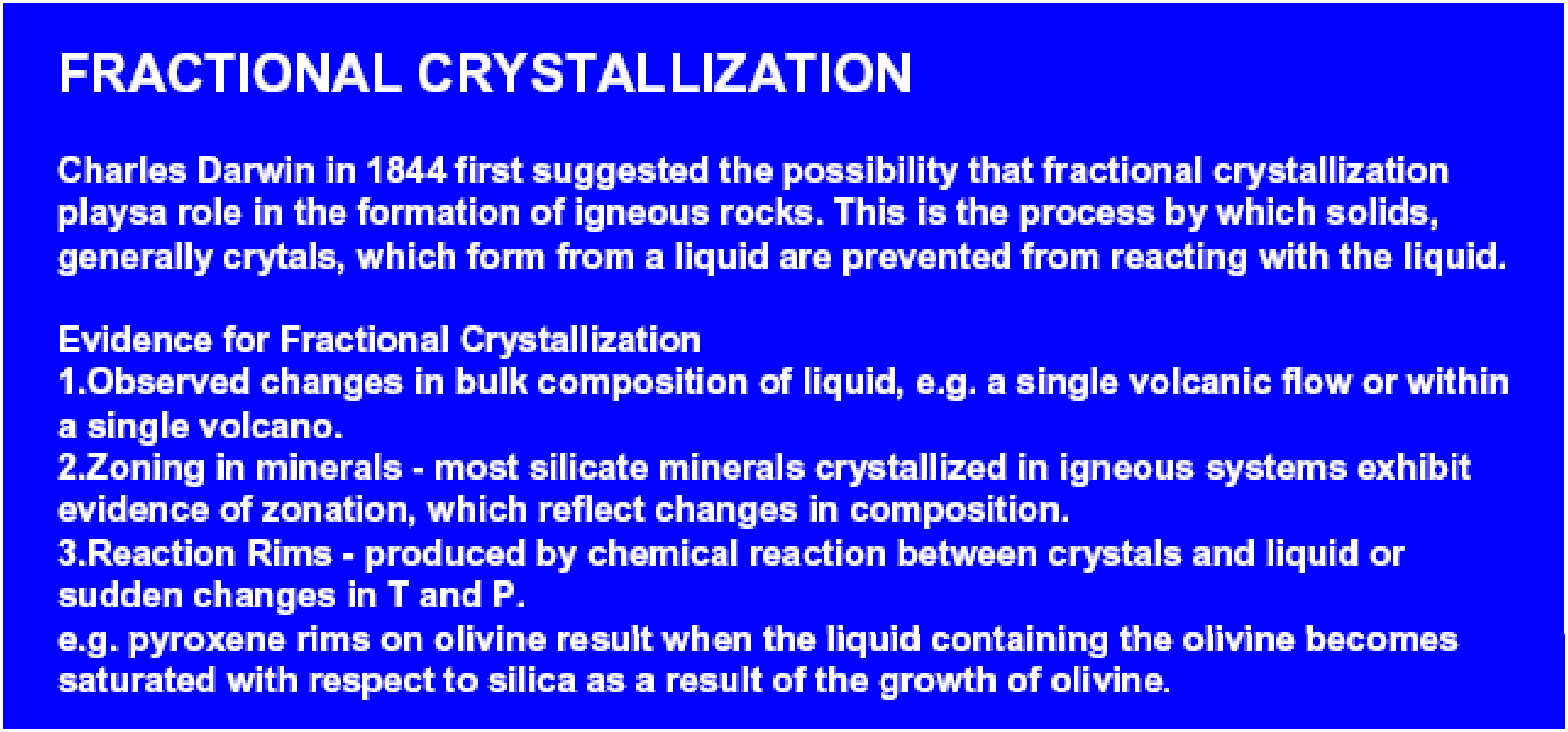
Magma chamber fills

Early formed mafic minerals crystallize and settle (or are otherwise separated from the residual melt)

The remaining melt is enriched in silica





FRACTIONAL CRYSTALLIZATION

Charles Darwin in 1844 first suggested the possibility that fractional crystallization playsa role in the formation of igneous rocks. This is the process by which solids, generally crytals, which form from a liquid are prevented from reacting with the liquid.

Evidence for Fractional Crystallization

1.Observed changes in bulk composition of liquid, e.g. a single volcanic flow or within a single volcano.

2.Zoning in minerals - most silicate minerals crystallized in igneous systems exhibit evidence of zonation, which reflect changes in composition.

3.Reaction Rims - produced by chemical reaction between crystals and liquid or sudden changes in T and P.

e.g. pyroxene rims on olivine result when the liquid containing the olivine becomes saturated with respect to silica as a result of the growth of olivine.

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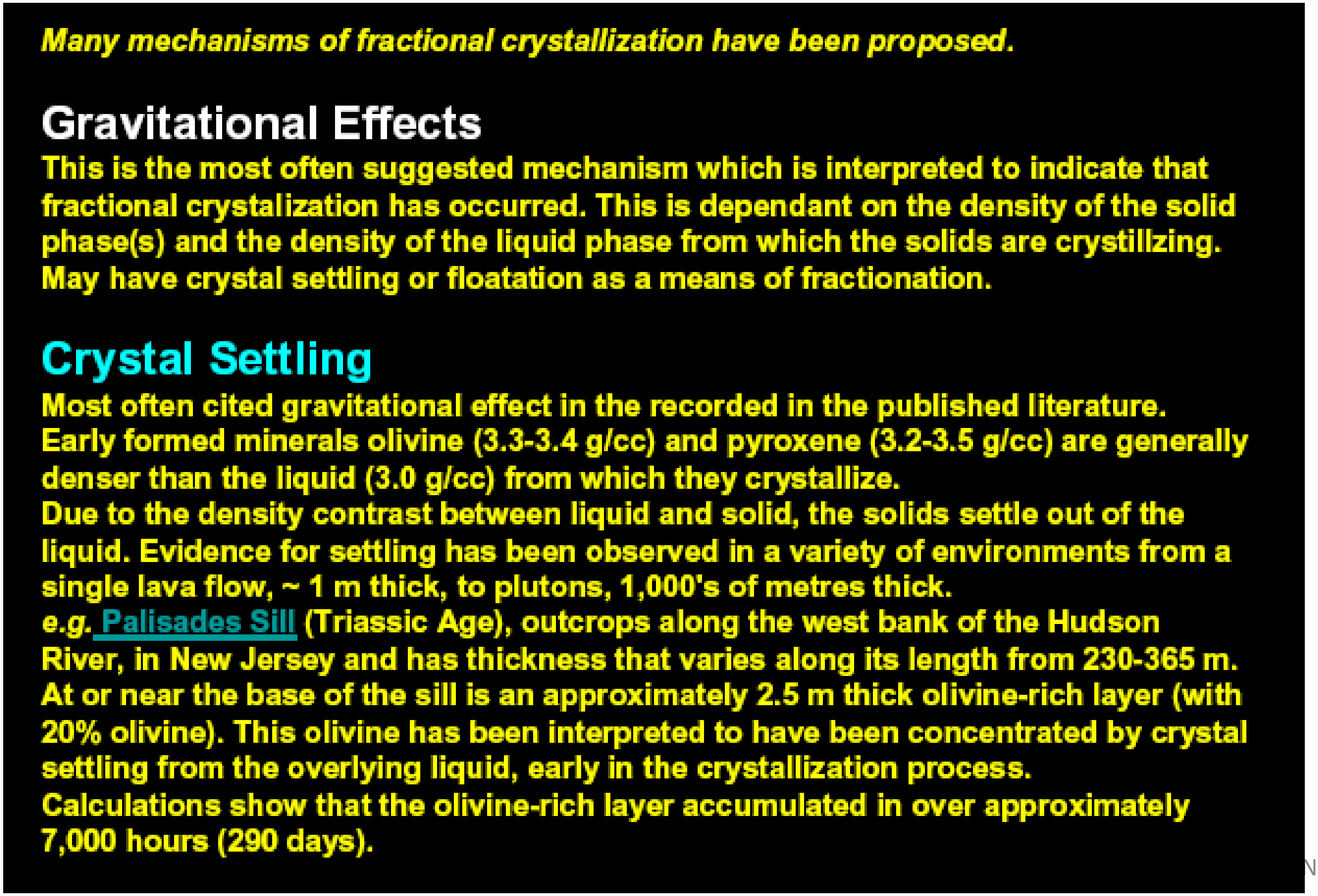


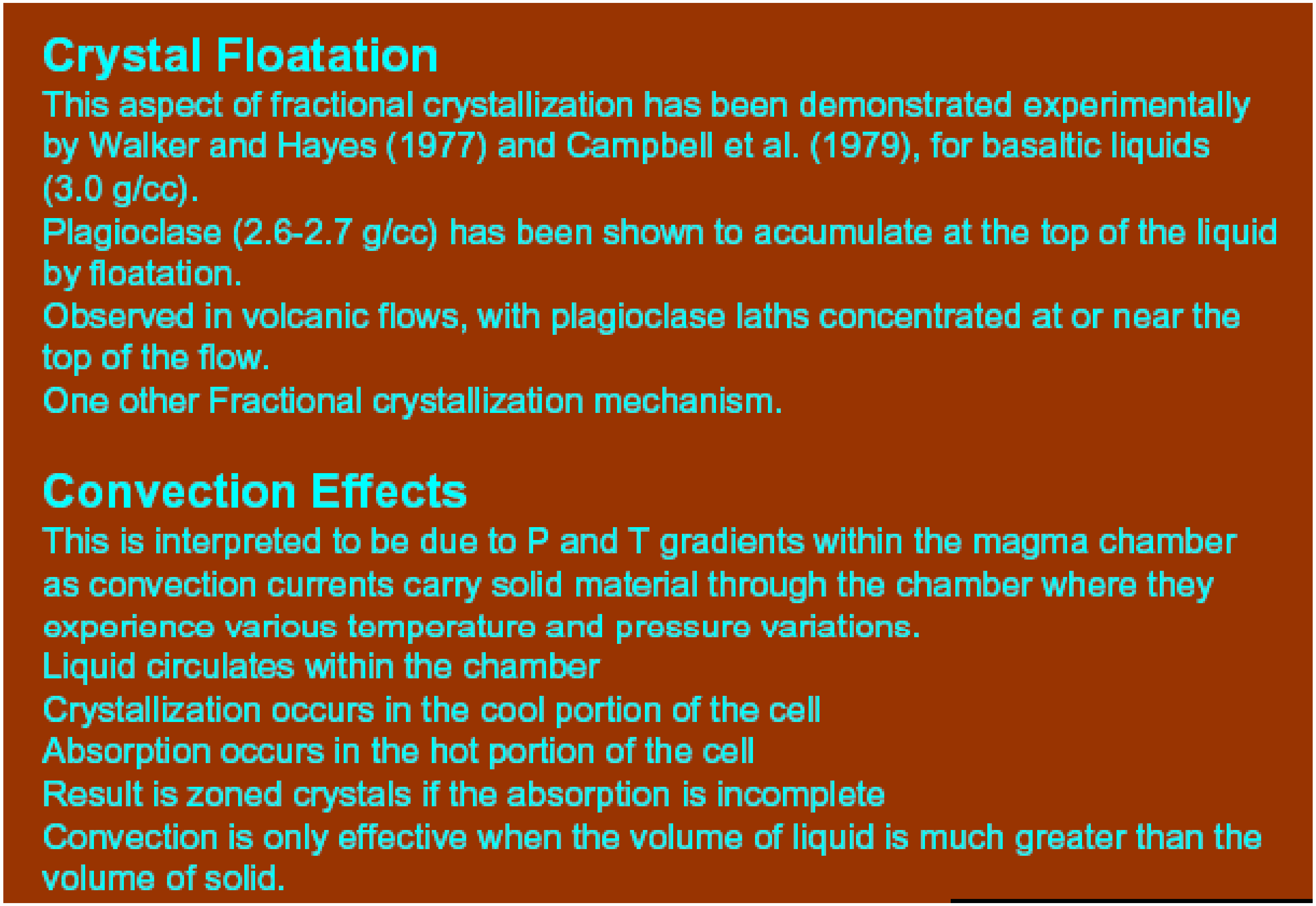
Many mechanisms of fractional crystallization have been proposed.

Gravitational Effects

This is the most often suggested mechanism which is interpreted to indicate that fractional crystalization has occurred. This is dependant on the density of the solid phase(s) and the density of the liquid phase from which the solids are crystillzing. May have crystal settling or floatation as a means of fractionation.

Crystal Settling

Most often cited gravitational effect in the recorded in the published literature.
Early formed minerals olivine (3.3-3.4 g/cc) and pyroxene (3.2-3.5 g/cc) are generally denser than the liquid (3.0 g/cc) from which they crystallize.
Due to the density contrast between liquid and solid, the solids settle out of the liquid. Evidence for settling has been observed in a variety of environments from a single lava flow, ~ 1 m thick, to plutons, 1,000's of metres thick.
***e.g.* Palisades Sill (Triassic Age), outcrops along the west bank of the Hudson River, in New Jersey and has thickness that varies along its length from 230-365 m. At or near the base of the sill is an approximately 2.5 m thick olivine-rich layer (with 20% olivine). This olivine has been interpreted to have been concentrated by crystal settling from the overlying liquid, early in the crystallization process.**
Calculations show that the olivine-rich layer accumulated in over approximately 7,000 hours (290 days).



Crystal Floatation

This aspect of fractional crystallization has been demonstrated experimentally by Walker and Hayes (1977) and Campbell et al. (1979), for basaltic liquids (3.0 g/cc).

Plagioclase (2.6-2.7 g/cc) has been shown to accumulate at the top of the liquid by floatation.

Observed in volcanic flows, with plagioclase laths concentrated at or near the top of the flow.

One other Fractional crystallization mechanism.

Convection Effects

This is interpreted to be due to P and T gradients within the magma chamber as convection currents carry solid material through the chamber where they experience various temperature and pressure variations.

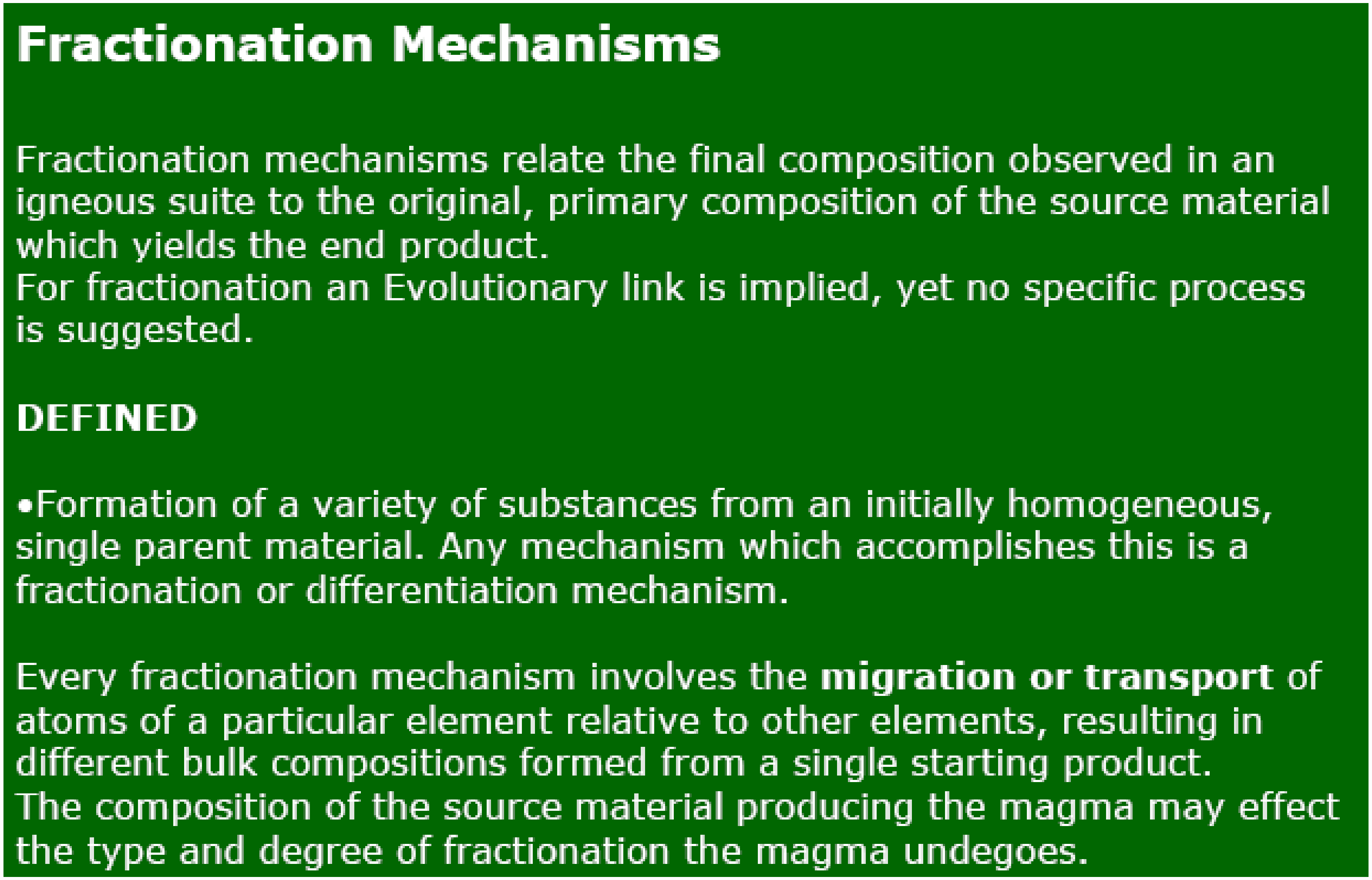
Liquid circulates within the chamber

Crystallization occurs in the cool portion of the cell

Absorption occurs in the hot portion of the cell

Result is zoned crystals if the absorption is incomplete

Convection is only effective when the volume of liquid is much greater than the volume of solid.



Fractionation Mechanisms

Fractionation mechanisms relate the final composition observed in an igneous suite to the original, primary composition of the source material which yields the end product.
For fractionation an Evolutionary link is implied, yet no specific process is suggested.

DEFINED

- Formation of a variety of substances from an initially homogeneous, single parent material. Any mechanism which accomplishes this is a fractionation or differentiation mechanism.

Every fractionation mechanism involves the **migration or transport** of atoms of a particular element relative to other elements, resulting in different bulk compositions formed from a single starting product.
The composition of the source material producing the magma may effect the type and degree of fractionation the magma undegoes.

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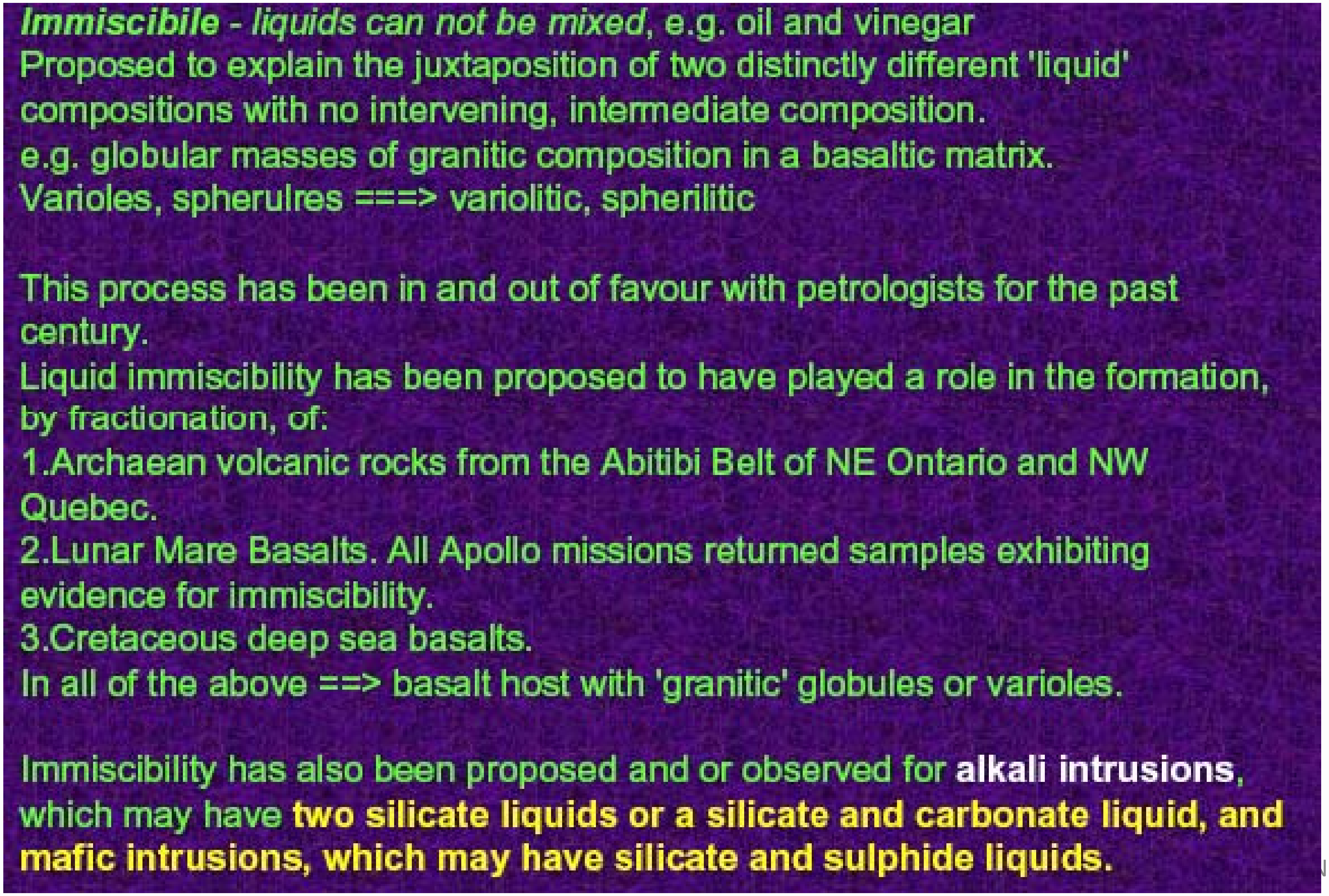
LIQUID IMMISCIBILITY



***Immiscibile** - liquids can not be mixed*, e.g. oil and vinegar
Proposed to explain the juxtaposition of two distinctly different 'liquid' compositions with no intervening, intermediate composition.
e.g. globular masses of granitic composition in a basaltic matrix.
Varioles, spherulres ===> variolitic, spherilitic

This process has been in and out of favour with petrologists for the past century.
Liquid immiscibility has been proposed to have played a role in the formation, by fractionation, of:
1.Archaean volcanic rocks from the Abitibi Belt of NE Ontario and NW Quebec.
2.Lunar Mare Basalts. All Apollo missions returned samples exhibiting evidence for immiscibility.
3.Cretaceous deep sea basalts.
In all of the above ==> basalt host with 'granitic' globules or varioles.

Immiscibility has also been proposed and or observed for **alkali intrusions**, which may have **two silicate liquids or a silicate and carbonate liquid, and mafic intrusions, which may have silicate and sulphide liquids.**